/200

Practical Application of Laboratory Data to Dairy Waste Treatment[a]

(Manuscript received July 5, 1957)

Nandor Porges

Eastern Regional Research Laboratory,[b]
Philadelphia 18 Pennsylvania

DISPOSAL OF WASTE is an important responsibility recognized by all branches of the food industry. The use of streams for direct disposal of waste is being restricted since a high percentage of surface waters is used for human consumption, for recreation, and for industrial purposes.

Milk handlers and processors must do their share in the control of pollution. Difficulties in treatment of dairy wastes led the dairy industry to request our Laboratory to make a study looking toward the alleviation of this pollution problem. The high oxygen demand of the dairy waste suggested to us that disposal might be achieved by aeration. Information obtained from this research may be applicable to other food wastes and help in the solution of a vexing problem. Details of our laboratory studies on the aerobic treatment of dairy wastes have been published *(9, 11, 12)*.

Sanitary engineers have shown that such laboratory data are useful in designing plants to treat industrial wastes *(2)*. Some of the principles that evolved from our studies and their application will be discussed in this paper.

The problem of the disposal of liquid wastes from food industries arises because they are considerably stronger than equal volumes of municipal wastes whose B.O.D. is only about 150 p.p.m. The application of aeration as used for the treatment of municipal wastes is usually not effective in the case of strong industrial wastes. A waste of a 1000 p.p.m. solids is actually a dilute solution containing only 0.1% solids and 99.9% pure water. This dilute material is not toxic, but it is excellent food for bacteria and causes disagreeable conditions when improperly handled. The harmful effects result from the lack of oxygen to satisfy the demands of the bacteria in the waste. If we assume that a milk or other food processing plant produces 50,000 gal. of waste a day with a concentration of 1000 p.p.m. solids, it may contain about 420 lb. of solids that will require treatment. About 300 lb. of oxygen will be required for stabilizing this waste; this is the amount of oxygen dissolved in about 4.5 million gal. of water. If this oxygen is not renewed, fish and plant life cannot exist. Natural waterways that have small flow volumes may have difficulty in replenishing the oxygen rapidly enough to maintain aerobic conditions with such concentrated wastes.

---

[a] Presented at the Seventeenth Annual Meeting of the Institute of Food Technologists, Pittsburgh, Pennsylvania, May 13, 1957.

[b] A laboratory of the Eastern Utilization Research and Development Division, Agricultural Research Service, U. S. Department of Agriculture.

RESULTS

In the course of our laboratory studies on the aeration of dairy waste, we found that a synthetic skim milk waste, fed and aerated continuously in laboratory equipment, was easily treated. Analyses showed that about 50% of the skim milk added as waste was completely destroyed and that the remainder was in the sludge *(4)*. Briefly the conversion may be expressed thus:

$$\text{Milk solids} + \text{oxygen} \longrightarrow \text{cells} + CO_2 + H_2O$$

This change occurred so rapidly that, in order to follow the changes, a chemical oxygen demand (C.O.D.) test was used *(10)* rather than the biochemical oxygen demand (B.O.D.) test. Knowing the C.O.D. of milk products, the various B.O.D. values could be approximated: for the skim milk the B.O.D. was 67% of the C.O.D.; for the lactose, 83%; for the whey, 54%; and for the well-aerated sludge, 40% *(13)*. Factors can be established as needed for other items.

Respiration studies were then conducted in a Warburg apparatus which showed that oxygen requirements were high for the first 6 hours when a one-dose addition of 1000 p.p.m. skim milk was acted upon by 500 p.p.m. sludge. Lactose and casein were readily removed from solution and the ratio of CO_2 evolved to O_2 utilized confirmed the idea that the waste was assimilated and oxidized *(3)*. However, complete oxidation did not occur as only about 37.5% of the calculated amounts of oxygen needed for complete combustion were used. Chemical analysis of the sludge gave the empirical formula $C_5H_7NO_2$ if ash, P and S are omitted *(5)*.

The following equations were developed to show the biological oxidation of skim milk which contains about 51% lactose and 37% protein. Complete oxidation of lactose is represented as follows:

$$C_{12}H_{22}O_{11} \cdot H_2O + 12\ O_2 \longrightarrow 12\ CO_2 + 12\ H_2O$$

For simplicity we may take one-twelfth of the lactose molecule and express the oxidation:

$$CH_2O + O \longrightarrow CO_2 + H_2O$$

Cell formation from the sugar may be expressed thus when ammonia is present:

$$5\ CH_2O + NH_3 \longrightarrow C_5H_7NO_2 + 3\ H_2O$$

However, our Warburg studies showed that only 37.5% of the theoretical amount of oxygen was converted to carbon dioxide while the remainder formed cell substances. Therefore, out of 8 available carbons, 3 or 37.5%, were oxidized. This information was written as follows to show cell formation from lactose:

$$3\ O_2 + 8\ (CH_2O) + NH_3 \longrightarrow C_5H_7NO_2 + 3\ CO_2 + 6\ H_2O$$

The utilization of casein for cell formation was also equated. In this case ammonia is liberated:

$$3\ O_2 + C_8H_{12}N_2O_3 \longrightarrow C_5H_7NO_2 + NH_3 + 3\ CO_2 + H_2O$$

Fortunately, the 240 units of sugar and the 184 units of casein required for the above equations are in the same proportion as found in skim milk. Hence, the two equations may be added. The ammonia liberated from the casein is used for lactose assimilation and the reaction remains neutral. The calculated yield, by adding the two equations, is 58%, slightly higher than found in our tests.

Addition gives this:

$$3\ O_2 + 8\ (CH_2O) + NH_3 \longrightarrow C_5H_7NO_2 + 3\ CO_2 + 6\ H_2O$$
$$3\ O_2 + C_8H_{12}N_2O_3 \longrightarrow C_5H_7NO_2 + 3\ CO_2 + H_2O + NH_3$$
$$6\ O_2 + 8\ (CH_2O) + C_8H_{12}N_2O_3 \longrightarrow 2\ C_5H_7NO_2 + 6\ CO_2 + 7\ H_2O$$

When assimilation is finished, the amount of oxygen required drops rapidly and oxygen utilization continues at the very slow rate of unfed cells. This endogenous respiration is represented by the following equation showing that 113 units of cells require 160 units of oxygen for complete combustion:

$$5\ O_2 + C_5H_7NO_2 \longrightarrow 5\ CO_2 + NH_3 + 2\ H_2O$$

The information may be tabulated as follows for waste of 1000 p.p.m. concentration:

Oxygen required for complete oxidation of 1 lb. of skim milk	1.20 lb.
Oxygen needed for assimilation (37.5%)	0.45 lb.
Time required for assimilation depends on cell concentration	
With 500 p.p.m. cells	6 hr.
With 1000 p.p.m. cells	3 hr.
Time decreases with increased sludge concentration.	
Oxygen required per hour depends on cell concentration	
With 500 p.p.m. cells	0.075 lb.
With 1000 p.p.m. cells	0.150 lb.
New cells or sludge produced	0.52 lb.
Oxygen for complete oxidation of new cells	0.75 lb.
Oxygen needed during first 24 hr. varies.	
If 1% oxidation per hr., then 20% per day	0.15 lb.
If 0.5% per hr., then 10% per day	0.075 lb.
Seed cells have respiration requirements.	
Oxygen to oxidize 1 lb. of organic matter	1.42 lb.
Oxygen to oxidize 20% per day	0.29 lb.
Oxygen to oxidize 10% per day	0.15 lb.

INDUSTRIAL APPLICATIONS

Pilot plant investigations conducted at Pennsylvania State University on 10,000 gal. of waste from the college creamery showed the validity of the laboratory data *(7)*. Difficulty was encountered in early studies when the customary aeration devices were used. The supply of available oxygen in solution was insufficient to satisfy the demands shown by the equations. The high oxygen demand of dairy wastes required aeration devices not ordinarily used for weaker wastes. Tests showed that when air was forced through a perforated pipe, only about 1% of the oxygen was dissolved as compared to 2–5% for porous plates. On the other hand, a specific type jet aerator, in which the liquid is pumped and air is sucked in from the atmosphere, showed 17–25% efficiency of oxygen usage *(8)*. Turbine type equipment using compressed air may give higher transfer efficiencies. The jet or aspirator device was satisfactory in treating dairy wastes at the pilot plant *(7)*. The efficiency of this device was increased to 40% when air was supplied to the air inlet under 6 lb. pressure.

A one-tank fill-and-draw treatment plant has been designed for a dairy having about 25,000 gal. of waste daily *(6)*. An average of 95% purification is reported. The tank is large enough to hold more than 34,000 gal. and has an effluent pipe at the 9,000-gal. level which is above the volume occupied by settled cells. This permits draining of 25,000 gal. of treated liquor.

Analyses showed that about 300 lb. of organic matter is present in the waste of this dairy. During the 8 hr. of waste flow, this amounts to 37.5 lb. per hr. and requires 37.5 x 0.45 or 16.9 lb. oxygen per hr. for assimilation. The 300 lb. of milk solids produce 150 lb. of new cells. Since sludge cells may destroy 20% of their own weight in 24 hours and since the new cells should replace old cells, 750 lb. of sludge should be carried in the aerator. By keeping such a balance, it is claimed that little or no sludge accumulates.

From the equations and data, 150 lb. of cells require 213 lb. oxygen or about 9.7 lb. per hr. for 22 hr. Therefore, while the waste is added, oxygen is supplied for assimilation and for endogenous respiration at a total of 16.9 + 9.7 or 26.6 lb. per hour. Then the cells are allowed to settle and the clear supernatant is drained. Aeration of the settled sludge is continued with 9.7 lb. oxygen per hr. until the next morning, when the cycle begins again with addition of fresh waste. When the special size jet aerator is used *(6)* and the liquid is recirculated at 60 gal. per min., each jet can dissolve 1.6 lb. of oxygen per hour from the air that is sucked through the jet. This waste disposal unit is practically automatic and has been in operation 3 years.

Units treating as little as 2,000 gal. of waste have been designed using only 2 or 3 jets. Large continuous flow units treating up to 150,000 gal. of milk processing wastes daily are in operation at Dushore, Pennsylvania, and at Horseheads, New York. The air is supplied at 6 p.s.i. pressure, the sludge is settled in a separate section and is pumped back to the aeration tank. The continuous treatment by jet aeration of 450,000 gal. of citrus waste containing about 3,600 p.p.m. soluble solids is underway at Winter Haven, Florida. The excess sludge in this case is hauled away as fertilizer. It is our understanding that over 60 installations based on the principle of rapid aeration are in use for the treatment of dairy wastes. The same principles of rapid aeration also have been applied to the treatment of other industrial wastes *(1)*.

LITERATURE CITED

1. Eckenfelder, W. W., Jr., and Grich, E. R. Plant scale studies on the biological oxidation of cannery wastes. *Proc. 10th Ind. Waste Conf. Purdue U.*, **549** (1955).
2. Eckenfelder, W. W., Jr., and O'Connor, D. J. Industrial waste process design. *Proc. Am. Soc. Civil Eng.*, **80** (411); 1 (1954).
3. Hoover, S. R., Jasewicz, L., Pepinsky, J. B., and Porges, N. Assimilation of dairy wastes by activated sludge. *Sewage and Ind. Wastes*, **23**, 167 (1951).
4. Hoover, S. R., and Porges, N. Treatment of dairy waste by aeration. II. Continuous aeration studies. *Proc. 5th Ind. Waste Conf., Purdue U.*, **137** (1949).
5. Hoover, S. R., and Porges, N. Assimilation of dairy wastes by activated sludge. II. The equation of synthesis and rate of oxygen utilization. *Sewage and Ind. Waste*, **24**, 306 (1952).
6. Kountz, R. R. Big problem: Dairy wastes. Striking solution: Bio-oxidation. *Food Eng.*, **26** (10 89 (1954).
7. Kountz, R. R. Dairy waste treatment plant design. *Biological Treatment of Sewage and Industrial Wastes.* J. McCabe and W. W. Eckenfelder, Jr., eds. Vol. I,

1956, Reinhold Publishing Corporation, New York, pp. 356–359.

8. Kountz, R. R. Evaluating proprietary aeration devices. *Biological Treatment of Sewage and Industrial Wastes.* Vol. I, 1956, pp. 212–214.
9. Porges, N. Waste treatment by optimal aeration—theory and practice in dairy waste disposal. *J. Milk and Food Tech.*, **19** (2): 34 (1956).
10. Porges, N., and Hoover, S. R. Treatment of dairy waste by aeration. I. Methods of study. *Proc. 5th Ind. Waste Conf., Purdue U.*, **130** (1949).
11. Porges, N., Jasewicz, L., and Hoover, S. R. A microbiological process report. Aerobic treatment of dairy wastes. *Applied Microbiol.*, **1**, 262 (1953).
12. Porges, N., Jasewicz, L., and Hoover, S. R. Principles in biological oxidation. *Biological Treatment of Sewage and Industrial Wastes.* J. McCabe and W. W. Eckenfelder, eds., Vol. I, 1956, Reinhold Publishing Corporation, New York, pp. 35–48.
13. Porges, N., Jasewicz, L., and Hoover, S. R. Simple method for estimating oxygen value of wastes. *Ind. Wastes,* **1**, 95 (1956).